**Figure IV-2-33. Estuary of the Sprague River, Maine (a small river facing the Gulf of Maine west of Popham Beach State Park). This is a typical New England salt marsh, with sinuous channels that alternately flood and drain depending on the stage of the tide. In the past, straight channels were often dug in such marshes to allow more efficient draining to reduce mosquito infestation**

- Barrier washover.
- Headlands.
- Eolian transport.
- In situ organic material (i.e., peat, plant detritus, and feces).
- Other terrestrial sources.

(4) Engineering problems. In light of growing concerns to preserve natural coastal marshes and the need to implement the national policy of "no net wetland losses," many agencies are researching ways to manage and implement wetland technology. Studies have identified numerous man-made and natural causes of wetland loss in the coastal zone:

(a) Sediment deficits. Man-made modifications of natural fluvial systems interfere with natural delta-building processes.

(b) Shoreline erosion. Along many marsh shorelines, the rates of retreat have increased because of hurricanes and other storms, engineering activities along the coast, and boating.

(c) Subsidence. Sinking of the land due to natural compaction of estuarine, lagoonal, and deltaic sediments results in large-scale disappearance of wetlands. This effect is exacerbated in some areas (e.g., Galveston Bay) by subsidence caused by groundwater and oil withdrawal.

(d) Sea level rise. Eustatic sea level rise is partially responsible for increased rates of erosion and wetland loss.

(e) Saltwater intrusion. Increased salinities in wetlands harm vegetation, which makes the wetlands more vulnerable to erosion.

(f) Canals. Canals increase saltwater intrusion and disrupt the natural water flow and sediment transport processes.

(5) Marsh restoration. Many agencies, including the U.S. Army Corps of Engineers, are conducting research in the building and restoration of marshes, are developing marsh management techniques, and are developing regulatory guidelines to minimize land loss. Under the Wetlands Research Program sponsored by the USACE, new technology in a multidisciplined approach is being developed. A useful publication is the “Wetlands Research Notebook” (U.S. Army Engineer Waterways Experiment Station 1992), which is a collection of technical notes covering eight field problem areas focusing on wetlands activities in support of USACE civil works projects.

## IV-2-12. Biological Coasts

*a. Introduction.*

(1) On many coasts, such as open wetlands, coral reef, and mangrove forest, biological organisms and processes are of primary importance in shaping the morphology. In contrast, on many other coasts, such as typical sandy beaches, biological activities do not appear to be of major significance when compared to the physical processes at work. Nevertheless, it is important to realize that biological processes are occurring on all shores; all man-made shoreline modifications must address the impact of the modification on the biological community.

(2) The types of organisms that can exist on a coast are ultimately controlled by interrelated physical factors. These include wave climate, temperature, salinity, frequency of storms, light penetration, substrate, tidal range, and the amounts of sediments and nutrients available to the system. Of these, the most important may be wave climate. The amount of wave energy dissipated at a shoreline per unit time ultimately has a dominant influence on whether the substrate is rock, sand, or silt; on the water clarity; on the delivery of nutrients; and, most importantly, on an organism’s physical design and lifestyle. The physical forces exerted by a large breaking wave are several orders of magnitude greater than the typical lateral forces affecting organisms in most other environments. For example, mangroves and salt marshes require low wave-energy climates to provide suitable substrate and to keep from being physically destroyed. On the other hand, reef-building corals require reasonably high wave-energy environments to maintain the water clarity, to deliver nutrients, to disperse larvae, to remove sediment, and to limit competition and predation.

(3) Another first-order physical condition controlling biological organisms is temperature. For example, this is the primary factor that restricts mangroves and coral reefs to the tropics. Also, the formation of ice in coastal waters has a major impact on Arctic communities.

(4) Unlike many physical processes on coastlines, biological processes are generally progradational in nature, extending shorelines seaward. Reef-building organisms produce hard substrate and sediments, in addition to sheltering areas behind the reefs. Some mollusks, calcareous algae (*Hallemeda sp.*, etc.), barnacles, echinoids, bryozoa, and worms produce significant amounts of sediment. Under low-energy

conditions in the deep sea and sheltered waters, diatoms and radiolaria produce sediments. Mangroves, salt marsh, and dune vegetation trap and stabilize sediments. The erosional effect of organisms that burrow into sediments or that bore into rocks is usually of lesser importance.

*b. High wave-energy coasts.* Higher plants have not evolved mechanisms to enable them to physically withstand high wave-energy environments. Thus, simple plants, mainly algaes, form the bases of the food chains for these marine coastal communities.

(1) Coral reefs. Coral reefs are massive calcareous rock structures that are slowly secreted by simple colonial animals that live as a thin layer on the rock surface. The living organisms continually build new structures on top of old, extending the reefs seaward toward deeper water and upward toward the surface. Reef-building corals have algae living within their tissues in a symbiotic relationship. The algae supplies food to the coral and the coral supplies shelter and metabolic wastes as nutrients to the algae. Shallow coral reefs worldwide occupy some 284,300 km$^2$, about 1.2 percent of the world's continental shelf area (Spalding, Ravilious, and Green 2001). While some corals are found in temperate and Arctic waters, reef-building corals are limited by water temperature to the tropics, mainly between the latitudes of 30 deg north and south. Bermuda, in the North Atlantic, warmed by the Gulf Stream, is the highest latitude location where active coral reefs are presently found. In the United States, coral reefs are found throughout the Florida Keys and the east and west coasts of Florida, in the Hawaiian Islands, the Pacific Trust Territories, Puerto Rico, and the Virgin Islands.

(a) Reef-building corals require clear water. The corals need to be free of sediments in order to trap food particles, and their algae require sufficient light for photosynthesis. While corals can remove a certain amount of sediment from their upper surfaces, heavy siltation will bury and kill them. Light penetration limits the depth of most reef-building corals to the upper 30-50 m, though some corals grow much deeper. The upper limit of reef growth is controlled by the level of low tide. Corals cannot stand more than brief exposures out of the water (for example, during the occasional passage of a deep wave trough).

(b) While coral reefs produce rock structure, they also produce calcareous sediments. Waves and currents pulverize coral skeletons into sand-size particles. However, on many reefs, calcareous algae (Hallemeda sp.) produce a majority of the sediments. The crushed calcareous shells of other animals, such as mollusks, sea urchins, and sand dollars, also provide sediment.

(c) Coral reefs rival tropical rain forests as being among the most complex communities on earth, and rock-producing reef communities are among the most ancient life forms found in the fossil record. Because of their complexity, the dynamics of coral reefs are not yet well understood. At least 100,000 species have been named and described, but the total number inhabiting the world's reefs may exceed one million species. Scientific knowledge of the ecology of reefs has almost entirely accumulated over the last 50 years, since the development of underwater scuba breathing apparatus in the 1940's.

(d) One of the critical ecological issues of our times is the rapid degradation of coral reefs around the world by various natural and human activities. Corals are highly sensitive to increases in temperature, exhibiting a stress response known as coral bleaching. In 1998, a global mass bleaching caused mass mortalities in many areas. Worldwide, however, humans are driving more profound changes to reefs than are natural phenomena. The most widespread impacts are water pollution, dredge and fill operations, over-harvesting of fish and shellfish, and the harvesting of some corals for jewelry. For example, in Indonesia, the world's largest coral nation, 82 percent of the corals are at risk from the illegal practice of dynamite fishing (which is also devastating to fish populations). Even far from the coast, deforestation, urban sprawl, and sloppy agriculture produce vast quantities of sediment and pollution that enter the sea and degrade reefs in the vicinity of river mouths.

(e) Controlled dredging around reefs is possible and is done routinely, causing minimal impact to reef communities. Mechanical damage (from cutter heads, chains, anchors, and pipelines) is often of equal or greater concern than suspended sediment production. Improvements in navigation and positioning have made dredging near reefs more viable. Nevertheless, careful monitoring is mandated in most cases.

(f) Reefs are of major economic importance to the communities along which they are located. For millenia, coastal peoples relied on coral reefs as a source of food. Spurgeon (1992) classifies their economic benefits as:

* Direct extractive uses - fisheries, building material.

* Direct non-extractive uses - tourism.

* Indirect uses - biological support for a variety of other ecosystems.

Reef tourism is now a major global industry. Diving tourism is ubiquitous and now occurs in 91 countries and states (Spalding, Ravilious, and Green 2001). One major benefit of mass tourism is that it had brought to public consiousness the issues of the fragility of reef ecosystems and the need to preserve the world's remaining reefs. Marine protected areas are becoming a critical tool in the preservation of remaining reefs, and some 660 protected areas worldwide incorporate reefs. Tourist income is helping some remote communities police and protect their reefs. The downside of mass tourism is the haphazard growth of infrastructure along the shore. Many vacation communities are built on remote coasts where resources, such as fresh water, are scarce and where trash and sewage effluent are not properly managed.

(g) An additional benefit of reefs is the shelter from waves that they provide to adjacent shores. As an example, the south and southwestern coast of Sri Lanka is battered by waves that travel unhindered across the Indian Ocean. In the past, the coral reefs that surrounded the coast served as buffers against the intense wave energy. But illegal reef breaking and coral mining, combined with negative impacts of tourism and development (sewage, agricultural pollution, physical damage) have greatly reduced the effectiveness of the reef barriers. As a result, much of the Sri Lankan south coast is now experiencing severe erosion (Young and Hale 1998).

(h) Stoddard (1969) has identified four major forms of large-scale coral reef types: fringing reefs, barrier reefs, table reefs, and atolls.

(i) *Fringing reefs* generally consist of three parts: a fore reef, a reef crest, and a back reef. The *fore reef* usually rises steeply from deep water. It may have spur and groove formations of coral ridges interspersed with sand and rubble channels. The *reef crest* usually forms a continuous wall rising to the low tide level. This usually occurs within a few hundred meters from shore. The seaward side of this area, called the *buttress zone*, receives the brunt of the wave action. Between the reef crest (or flat) and the shoreline, the reef usually deepens somewhat in the back reef area. This area typically contains much dead coral as well as rock, rubble, sand, and/or silt. It also contains live coral heads, algae, eel grass, etc. Fringing reefs form as the beginning stages in the evolution of atolls and possibly barrier reefs.

(j) *Barrier reefs* grow on the continental shelf where suitable solid substrate exists to serve as a foundation. Their form is typically a long coral embankment separated from the mainland by a lagoon that may be several kilometers wide. The lagoon is usually flat-floored and may be as much as 16 km wide and 35 to 75 m in depth. Although similar to fringing reefs, barrier reefs are much more massive, the reef crests are much further from shore, and the back reef areas are deeper. Protected shorelines behind barrier reefs are characterized by mangrove swamps and are usually progradational. The seafloor on the seaward side slopes steeply away into deeper water and is covered by coral rubble.

(k) *Table reefs* grow from shallow banks on the seafloor that have been capped with reef-forming organisms. They cover extensive areas but do not form barriers or enclose lagoons.

(l) *Atolls* are ring-shaped reefs that grow around the edges of extinct volcanic islands, enclosing lagoons of open water. The shallow lagoons may contain patch reefs. Atolls are primarily found in isolated groups in the western Pacific Ocean. Small low islands composed of coral sand may form on these reefs. These islands may hold enough of a fresh water lens to support human life, but the islands are quite vulnerable to inundation and to tropical storms. The first theory concerning the development of atolls, the subsidence theory proposed by Charles Darwin in 1842, has been shown to be basically correct (Strahler 1971). Figure IV-2-34 illustrates the evolution of an atoll.

(m) The development of atolls begins with an active volcano rising from the ocean floor and forming a volcanic island. As the volcano ceases activity, a fringing reef forms along the shore. Over geologic time, erosion of the volcanic island and subsidence due to general aging of the ocean basin cause the island to drop below sea level. The actively growing fringing reef keeps pace with the subsidence, building itself upward until a barrier reef and lagoon are formed. As the center of the island becomes submerged, the reef continues its upward growth, forming a lagoon. During the development, the lagoon floor behind the reef accumulates coral rubble and other carbonate sediments, which eventually completely cover the subsiding volcanic island.

(2) Worm reefs. A type of biogenic reef that is not related to coral reefs is that produced by colonies of tubeworms. Serpulid worms and Sabellariid worms are two types known to form significant reef structures by constructing external tubes in which they live. The Serpulids build their tubes from calcareous secretions and the Sabellariids by cementing particles of sand and shell fragments around their bodies. Colonies of these worms are capable of constructing massive structures by cementing their tubular structures together. As new tubes are continually produced over old ones, a reef is formed. These reefs typically originate from a solid rocky bottom, which acts as an anchoring substrate. Worm reefs are most commonly found in sub-tropical and tropical climates (e.g., east coast of Florida). Reefs of this nature can play an important role in coastal stabilization and the prevention of coastal erosion.

(3) Oyster reefs. Oysters flourish under brackish water conditions in lagoons, bays, and estuaries. The oysters cement their shells to a hard stable substrata including other oyster shells. As new individuals set onto older ones, a reef is formed. These reefs can form in temperate as well as tropic waters.

(a) Oysters found around the United States are part of the family *Ostreidae*. The Eastern, or American oyster (*Crassostrea virginica*) is distributed along the entire east coast of North America from the Gulf of St. Lawrence through the Gulf of Mexico to the Yucatan and the West Indies. The other major North American species is *Ostrea lurida*, which ranges along the Pacific coast from Alaska to Baja California (Bahr and Lanier 1981).

(b) Intertidal oyster reefs range in size from isolated scattered clumps a meter high to massive solid mounds of living oysters anchored to a dead shell substrate a kilometer across and 100 m thick (Pettijohn 1975). Reefs are limited to the middle portion of the intertidal zone, with maximum elevation based on a minimum inundation time. The uppermost portion of a reef is level, with individual oysters pointing upwards. At the turn of the century, vast oyster flats were found along the Atlantic coast in estuaries and bays. In South Carolina, the flats covered acres and sometimes square miles (cited in Bahr and Lanier (1981)).

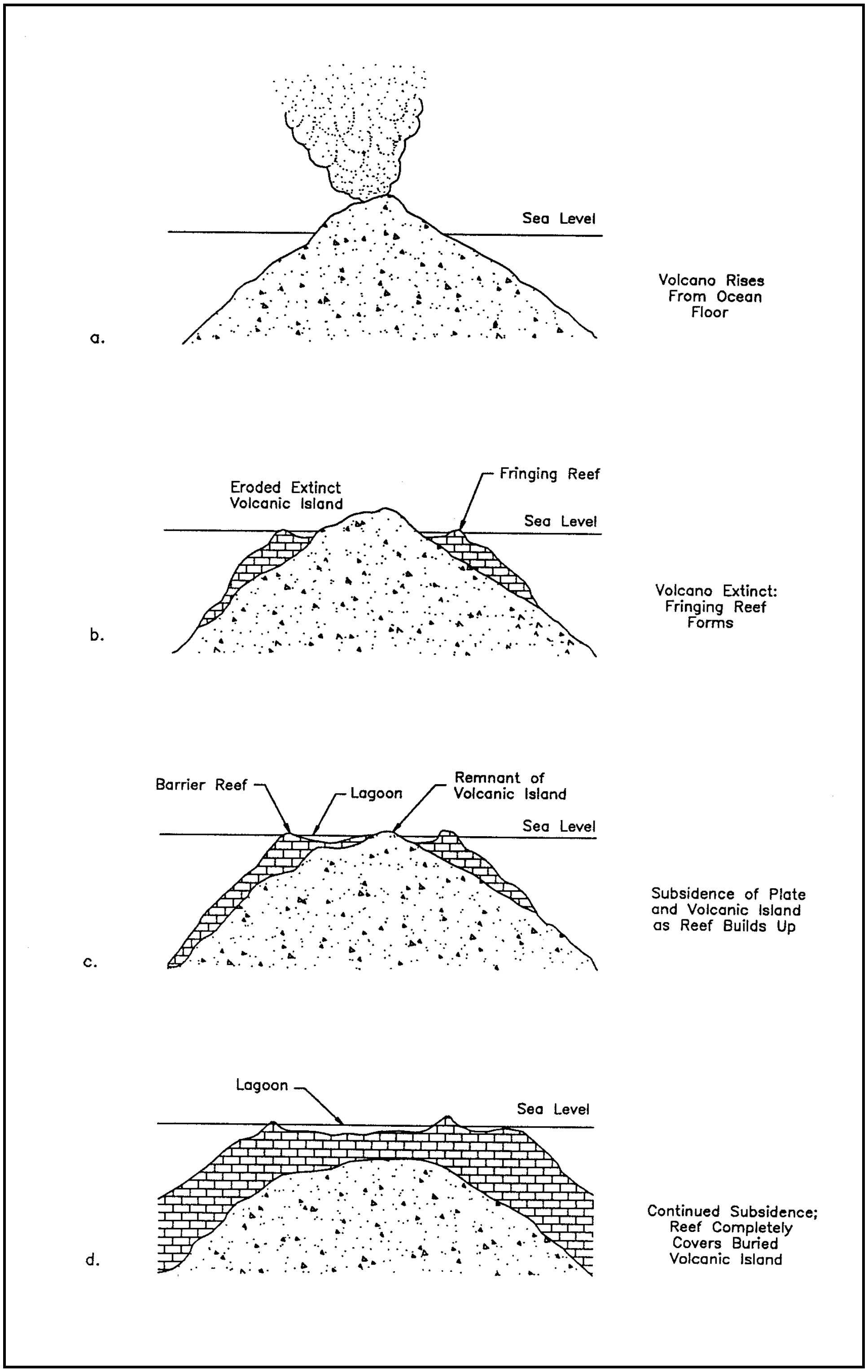


**Figure IV-2-34. Evolution of a coral island: (a) Active volcano rising from the seafloor, (b) Extinct volcanic island with fringing reef, (c) Subsiding island; reef builds upward and seaward, forming barrier reef, (d) Continued subsidence causing remnant volcanic island to be completely submerged. Growth continues upward and seaward until remnant volcano is covered (adapted from Press and Siever (1986))**

(c) Oyster reefs serve an important biological role in the coastal environment. The reefs are a crucial habitat for numerous species of microfauna and macrofauna. The rough surface of a reef flat provides a huge surface area for habitation by epifauna, especially vital in the marsh-estuarine ecosystem that is often devoid of other hard substrate. The high biological productivity of reef environments underscores one of the reasons why reefs must be protected and preserved.

(d) Oyster reefs play important physical and geological roles in coastal dynamics because they are wave-resistant structures that can biologically adapt to rising sea level. Reefs affect the hydrologic regime of salt marsh estuaries in three ways: by modifying current velocities, by passively changing sedimentation patterns, and by actively augmenting sedimentation by biodeposition. (Biological aggradation increases the size of suspended particles and increases their settling rates.) As reefs grow upward and laterally, modify energy fluxes by damping waves and currents, and increase sedimentation, they ultimately produce major physiographic changes to their basins. These changes can occur on short time scales, on the order of hundreds of years (Bahr and Lanier 1981). During geologic history, massive reefs have accumulated in many areas, some of which became reservoirs for oil and gas.

(e) Although oysters are adapted to a wide range of temperature, turbidity, and salinity conditions, they are highly susceptible to man-made stresses. These stresses on oyster communities can be classified into eight categories (Bahr and Lanier 1981):

- Physical sedimentation, especially from dredging or boat traffic.
- Salinity changes due to freshwater diversion or local hydrologic alterations.
- Eutrophication (oxygen depletion) due to algae growth in water that is over-enriched with organic matter.
- Toxins from industrial and urban runoff.
- Physical impairment of feeding structures by oil.
- Thermal loading, primarily from power plants.
- Overharvesting.
- Loss of wetlands.

There has been a recorded significant decline in the health and extent of living United States east coast oyster reefs since the 1880's, although the data are sometimes conflicting because ground-level surveys are difficult to conduct (Bahr and Lanier 1981). It is easy to account for the declines of reefs near population and industrial centers, but the declines are more difficult to explain in more pristine areas of the coast (e.g. the Georgia coast near Sapelo Island). Population changes may be due, in part, to natural cycles of temperature and salinity or fecundity.

(f) Because oyster reefs are susceptible to fouling and silting, it is important that geologists and engineers consider sediment pathways during the planning phases of coastal construction and dredging projects or stream diversion and other watershed changes. As discussed earlier, dredging near reefs is technically feasible as long as careful technique is observed and environmental conditions are monitored.

(g) In summary, oyster reefs serve critical biological and physical purposes in the estuarine and coastal marsh environment. They enhance biological productivity, provide stable islands of hard substrate in otherwise unstable soft muddy bottoms, modify hydrodynamic flows and energy fluxes. With respect to shore protection, reefs are a biological wave damper that can accommodate rising sea level as long as they are alive. It is essential that reefs be protected from wanton destruction by pollution and other stresses imposed by human development.

(4) Rocky coasts.

(a) Kelp beds. Kelp forests are formed by various species of algae that attach to hard substrate with a root-like system called a *holdfast*. Some (prominently *Macrosistus sp.*) can grow many tens of meters in length up to the water surface, where their tops float and continue to grow. The plants are quite rubbery and can withstand significant wave action. Kelp beds are found along rocky shorelines having cool clear water. In North America, they occur along much of the Pacific coast and, to a lesser extent, along the North Atlantic coast. Kelp beds are, to some extent, the functional temperate latitude counterpart of coral reefs (Carter 1988).

(b) Kelp biological communities. Kelp beds harbor extensive biological communities that include fish, sea otters, lobster, starfish, mollusks, abalones, and many other invertebrates. In addition, kelp beds absorb wave energy, helping to shelter beaches. Man's main impact has been the commercial harvesting of various portions of this community, including the kelp. In the past, hunting sea otters for their pelts allowed sea urchins to multiply, and the overpopulation of sea urchins grazed and destroyed many beds. Today, the reestablishment of some sea otter populations has led to conflicts with shell fishermen. Water pollution is also a problem in some areas.

(c) Rock reefs and shorelines. Submerged rock reefs provide substantial habitat for organisms. They provide a place of attachment for sessile organisms, and the crevices provide living spaces and havens of refuge for mobile organisms such as fish and lobsters. These structures are a boon to sports fishermen, and many artificial reefs have been built on sandy seafloors out of a wide array of materials. Rocky shorelines have communities of organisms living in the intertidal and subtidal zones. These may or may not be associated with offshore kelp bed or coral reef communities.

(5) Sandy coasts. Much of the biological activity on sandy coasts is confined to algae, various invertebrates, and fish living within the water column. Of these, fish, shrimp, and crabs have the greatest economic importance. In addition, there are infaunal filter feeders, mainly mollusks and sand dollars, that live just beneath the sand surface.

(a) One important and often overlooked biological activity on some sandy beaches is their use as nesting areas by a variety of migratory animals. These include sea turtles, birds, marine mammals, and fish. In North America, many of these species are threatened or endangered, including all five species of sea turtles and some birds such as the piping plover, the snowy plover, and the least tern. For most of these species, their problems are directly related to conflicts with man's recreational use of beaches and the animals' inability to use alternate nesting sites. Fortunately, some states have implemented serious ecological programs to help save these threatened species. For example, Florida has rigorous laws preventing disruption of nesting turtles, and many Florida municipalities have found that maintaining healthy natural biological communities is an excellent way to lure tourists.

(b) Plants occupying sand dunes are characterized by high salt tolerance and long root systems that are capable of extending down to the freshwater table (Goldsmith 1985). Generally, these plants also generate rhizomes that grow parallel to the beach surface. Beach plants grow mainly in the back beach and dune areas beyond the zone of normal wave uprush. The plants trap sand by producing low energy conditions near the ground where the wind velocity is reduced. The plants continue to grow upward to keep pace with the accumulation of sand, although their growth is eventually limited by the inability of the roots to reach dependable water. The roots also spread and extend downward, producing a thick anchoring system that stabilizes the back beach and dune areas. This stabilization is valuable for the formation of dunes, which provide storm protection for the entire beach. The most common of these plants are typically marram grass, saltwort, American sea grass, and sea oats. With time, mature dunes may accumulate enough organic nutrients to support shrub and forest vegetation. The barrier islands of the U.S. Atlantic coast and the Great Lakes shores support various species of *Pinus*, sometimes almost to the water's edge.

*c*. *Low wave-energy coasts*. In locations where the wave climate is sufficiently low, emergent vegetation may grow out into the water. Protection from wave action is typically afforded by local structures, such as headlands, spits, reefs, and barrier islands. Thus, the vegetation is usually confined to the margins of bays, lagoons, and estuaries. However, in some cases, the protection may be more regional in extent. Some of the mangrove forests in the Everglades (south Florida) and some of the salt marshes in northwest Florida and Louisiana grow straight into the open sea. The same is true for freshwater marshes in bays and river mouths in the Great Lakes.

(1) General.

(a) Only a few higher plants possess a physiology that allows them to grow with their roots in soils that are continuously saturated with salt water. These are the mangroves of the tropics and the salt marsh grasses of the higher latitudes. The inability of other plants to compete or survive in this environment allows small groups of species or single species to cover vast tracts of some coastal areas. These communities typically show zonations with different species dominant at slightly different elevations, which correspond to different amounts of tidal flooding. The seaward limit of these plants is controlled by the need for young plants to have their leaves and branches above water. To this end, some mangroves have seedlings that germinate and begin growing before they drop from the parent tree. Upland from these communities, a somewhat larger number of other plants, such as coconuts and dune grasses, are adapted to live in areas near, but not in, seawater.

(b) Understanding and appreciation of the importance of these types of coastal areas are growing. Former attitudes that these areas were mosquito-infested wastelands imminently suitable for dredge- and-fill development are being replaced by an appreciation of their great economic importance as nursery grounds for many species of fish and shellfish, of their ability to remove pollutants, of their ability to protect upland commercial development from storms, of their fragility, and of their beauty.

(2) Mangroves.

(a) *Mangroves* include several species of low trees and shrubs that thrive in the warm, shallow, saltwater environments of the lower latitudes. Worldwide, there are over 20 species of mangroves in at least 7 major families (Waisel 1972). Of these, the red, white, and black mangroves are dominant in south Florida and the Caribbean. They favor conditions of tidal submergence, low coastal relief, saline or brackish water, abundant fine sediment supply, and low wave energy. Mangroves have the ability to form unique intertidal forests that are characterized by dense entangled networks of arched roots that facilitate trapping of fine sediments, thereby promoting accretion and the development of marshlands. The *prop roots* and *pneumatophores* also allow the plants to withstand occasional wave action and allow oxygen to reach the roots in anaerobic soils. The prime example in the United States is the southwest shore of Florida, in the Everglades National Park.

(b) Mangrove coasts are crucial biological habitats to a wide variety of invertebrates, fish, birds, and mammals. In the past, the primary cause of their destruction has been dredge-and-fill operations for the reclamation of land and for mosquito control.

*d. Other sources of biogenic sediment in the coastal zone*. In areas of high biological activity, organically derived sediments may account for a significant proportion of the sediment composition, especially where terrigenous sediment supplies are low. These biogenic materials, consisting of remains of plants and animals and mineral matter produced by plants and animals, accumulate at beaches, estuaries, and marshlands.

(1) The most familiar types of biogenic sediments are hard calcareous skeletal parts and shell fragments left behind by clams, oysters, mussels, corals, and other organisms that produce calcareous tests. In tropical climates, the sediment commonly consists of coral fragments and calcareous algal remains. Siliceous tests are produced by most diatoms and radiolaria. Sediments predominately containing carbonate or calcareous material are generally referred to as *calcarenites*, while sediments composed predominantly of siliceous matter are referred to as *diatomites* or *radiolarites*, depending upon which organism is most responsible for the sediment (Shepard 1973). In the Great Lakes and some inland U.S. waterways, the zebra mussel has proliferated since the mid-1980's, and now some shorefaces are covered with mussel shell fragments to a depth of over 10 cm. The mussels are a serious economic burden because they choke the inlets of municipal water systems and coolant pipes.

(2) In some areas, wood and other vegetation may be introduced into the sediments in large quantities. This is especially common near large river mouths and estuaries. This organic material may become concentrated in low energy environments such as lakes and salt marshes, eventually producing an earthy, woody composition known as *peat* (Shepard 1973). Peat exposed on the shoreface has been used as an indicator of marine transgression and barrier island retreat (Figure IV-2-35) (Dillon 1970). In Ireland and Scotland, peat is dried and used as a fuel.

## IV-2-13. Continental Shelf Geology and Topography

*a. Introduction.* The geology of the world's continental shelves is of direct significance to coastal engineers and managers in two broad areas. First, the topography of the shelf affects coastal currents and wave climatology. Wave refraction and circulation models must incorporate shelf bathymetry. Bathymetry was incorporated in the wave hindcast models developed by the USACE Wave Information Study (See references in Part II-8). Second, offshore topography and sediment characteristics are of economic importance when offshore sand is mined for beach renourishment or dredged material is disposed offshore.

*b. Continental shelf sediment studies.*

(1) The Inner Continental Shelf Sediment and Structure (ICONS) study was initiated by the Corps of Engineers in the early 1960's to map the morphology of the shallow shelf and find sand bodies suitable for beach nourishment. This program led to a greater understanding of shelf characteristics pertaining to the supply of sand for beaches, changes in coastal and shelf morphology, longshore sediment transport, inlet migration and stabilization, and led to a better understanding of the Quaternary shelf history. ICONS reports are listed in Table IV-2-5.

**Figure IV-2-35. Peat horizon exposed on the shoreface, Ditch Plains, Long Island, New York (March 1998). The peat is in-situ, indicating that lagoonal sediments accumulated here before the barrier beach retreated over the marsh. The peat layer was about 1 m above the ocean water level at the time the photograph was taken. The dune resting on the peat is about 2 m thick**

(2) Since the 1970's, the Minerals Management Service (MMS), a bureau of the U.S. Department of the Interior, has been tasked with managing the mineral resources of the Outer Continental Shelf. In conducting its mission, the MMS has sponsored many surveys and studies of mineral resources on the continental shelf. These studies can be accessed via the MMS' Environmental Studies Program Information System (ESPIS) at:

http://mmspub.mms.gov/espis/

(3) For beach renourishment projects, U.S. Army Corps of Engineers Districts typically obtain information on sand resources near the proposed project area from various sources:

(a) In-house studies, typically from vibracoring or rotary borings.

(b) Contracts with marine geophysics/geotechnical surveyors.

(c) The U.S. Geological Survey.

**Table IV-2-5**
**U.S. Army Corps of Engineers Inner Continental Shelf Sediment and Structure (ICONS) Reports**

| Location | References[1] |
|---|---|
| **Atlantic Coast** | |
| Massachusetts Bay | Meisburger 1976 |
| New York - Long Island Sound | Williams 1981 |
| New York - Long Island shelf | Williams 1976 |
| New York Bight | Williams and Duane 1974 |
| New Jersey - central | Meisburger and Williams 1982 |
| New Jersey - Cape May | Meisburger and Williams 1980 |
| Delaware, Maryland, Virginia | Field 1979 |
| Chesapeake Bay entrance | Meisburger 1972 |
| North Carolina - Cape Fear | Meisburger 1977; Meisburger 1979 |
| Southeastern U.S. shelf | Pilkey and Field 1972 |
| Florida - Cape Canaveral to Georgia | Meisburger and Field 1975 |
| Florida - Cape Canaveral | Field and Duane 1974 |
| Florida - Palm Beach to Cape Kennedy | Meisburger and Duane 1971 |
| Florida - Miami to Palm Beach | Duane and Meisburger 1969 |
| **Gulf of Mexico** | |
| Texas - Galveston County | Williams, Prins, and Meisburger 1979 |
| **Lake Erie** | |
| Pennsylvania | Williams and Meisburger 1982 |
| Ohio | Williams et al. 1980; Carter et al. 1982 |
| **Lake Michigan** | |
| Southeast shore | Meisburger, Williams, and Prins 1979 |
| **Sampling tools and methods** | |
| Pneumatic coring device | Fuller and Meisburger 1982 |
| Vibratory samplers | Meisburger and Williams 1981 |
| Data collection methods | Prins 1980 |

[1] Complete citations are listed in Appendix A

(d) U.S. Army Engineer Research and Development Center, Waterways Experiment Station.

(e) State and local agencies.

New geographic data collected by the Federal Government is documented with Metadata that can be accessed from various computer servers. Unfortunately, there is no consistent method of cataloging historical data or reports. Users who need information on sand resources near the coast must contact the Corps District responsible for that particular area.

*c. Continental shelf morphology.* Surficial sediment on the continental shelves is largely dependent upon the type of coast (i.e. collision, or leading, versus trailing) and the presence of rivers that supply material to the coast.

(1) Leading edge shelves, such as the Pacific coasts of North and South America, are typically narrow and steep. Submarine canyons, which sometimes cut across the shelves almost to the shore (Shepard 1973), serve as funnels that carry sediment down to the abyssal plain. Normally, very little sand is available offshore.

(2) Trailing edge shelves are, in contrast, usually wide and flat, and the heads of canyons usually are located a considerable distance from shore. Nevertheless, a large amount of sediment is believed to move down these canyons (Emery 1968). Off the United States Atlantic coast, the broad continental shelf contains a vast amount of sand. Unfortunately, much of this sand is not available for beach renourishment because it is either too far from shore or its composition is incompatible with the beaches where it is to be placed (i.e., contains too much rock, shell fragment, mud, or organic material or the grain size is different than the size of the native material where it is to be placed).

*d. Examples of specific features - Atlantic seaboard.*

(1) The continental shelf of the Middle Atlantic Bight of North America, which is covered by a broad sand sheet, is south of the region directly influenced by Pleistocene glacial scouring and outwash. This sand sheet is divided into broad, flat, plateau-like compartments dissected by shelf valleys that were excavated during the Quaternary lowstands of the sea. Geomorphic features on the shelf include low-stand deltas (cuspate deltas), shoal and cape retreat massifs (bodies of sand that formed during a transgressive period), terraces and scarps, cuestas (asymmetric ridges formed by the outcrop of resistant beds), and sand ridges (Figure IV-2-36) (Swift 1976; Duane et al. 1972).

(2) The larger geomorphic features of the Middle Atlantic Bight are constructional features molded into the Holocene sand sheet and altered in response to storm flows. Off the coasts of Delaware, Maryland, and Virginia, shoreface-connected shoals appear to have formed in response to the interaction of south-trending, shore-parallel, wind-generated currents with wave- and storm-generated bottom currents during winter storms. Storm waves aggrade crests, while fair-weather conditions degrade them. A second shoal area further offshore at the 15-m depth is indicative of a stabilized sea level at that elevation. These shoals may be suitable sources of sand for beach renourishment. However, the often harsh wave conditions off the mid-Atlantic seaboard may limit the economic viability of mining these shoals. The origin and distribution of Atlantic inner shelf sand ridges are discussed in McBride and Moslow (1991).

(3) Linear shoals of the Middle Atlantic Bight tend to trend northeast (mean azimuth of 32 deg) and extend from the shoreline at an angle between 5 and 25 deg. Individual ridges range from 30 to 300 m in length, are about 10 m high, and have side slopes of a few degrees. The shoal regions extend for tens of kilometers. The crests are composed of fine-medium sand, while the ridge flanks and troughs are composed of very fine-fine sand. The mineralogy of shoals reflects that of the adjacent beaches.

*e. Riverine influence.*

(1) Rivers provide vast amounts of sediment to the coast. The 28 largest rivers of the world, in terms of drainage area (combined size of upland drainage area and subaerial extent of deltas), discharge across trailing-edge and marginal sea coasts (Inman and Nordstrom 1971). Because the larger rivers drain onto trailing edge coasts, these shores tend to have larger amounts of available sediment, which is deposited across a wide continental shelf. The sediment tends to remain on the shelf and is only lost to the abyssal plains when deltas prograde out across the continental rise (e.g., the Mississippi and Nile Deltas) or when submarine canyons are incised across the shelf (e.g., Hudson River sediment funnels down the Hudson Canyon).

(2) The Columbia River, which is the 29th largest river in the world, is the largest one to drain across a collision coast. Until dams were built during the mid-20th century, the Columbia carried a major sediment load, which was deposited on the ebb shoal off its mouth. This shoal provided the sand that formed the Long Beach peninsula and fed the beaches as far north as the Olympic Peninsula. The Columbia appears to be an exception - on most collision coasts, canyons frequently cut across the shelf almost to the shore (Shepard 1973), therefore resulting in the direct loss of sediment from the coastal zone.

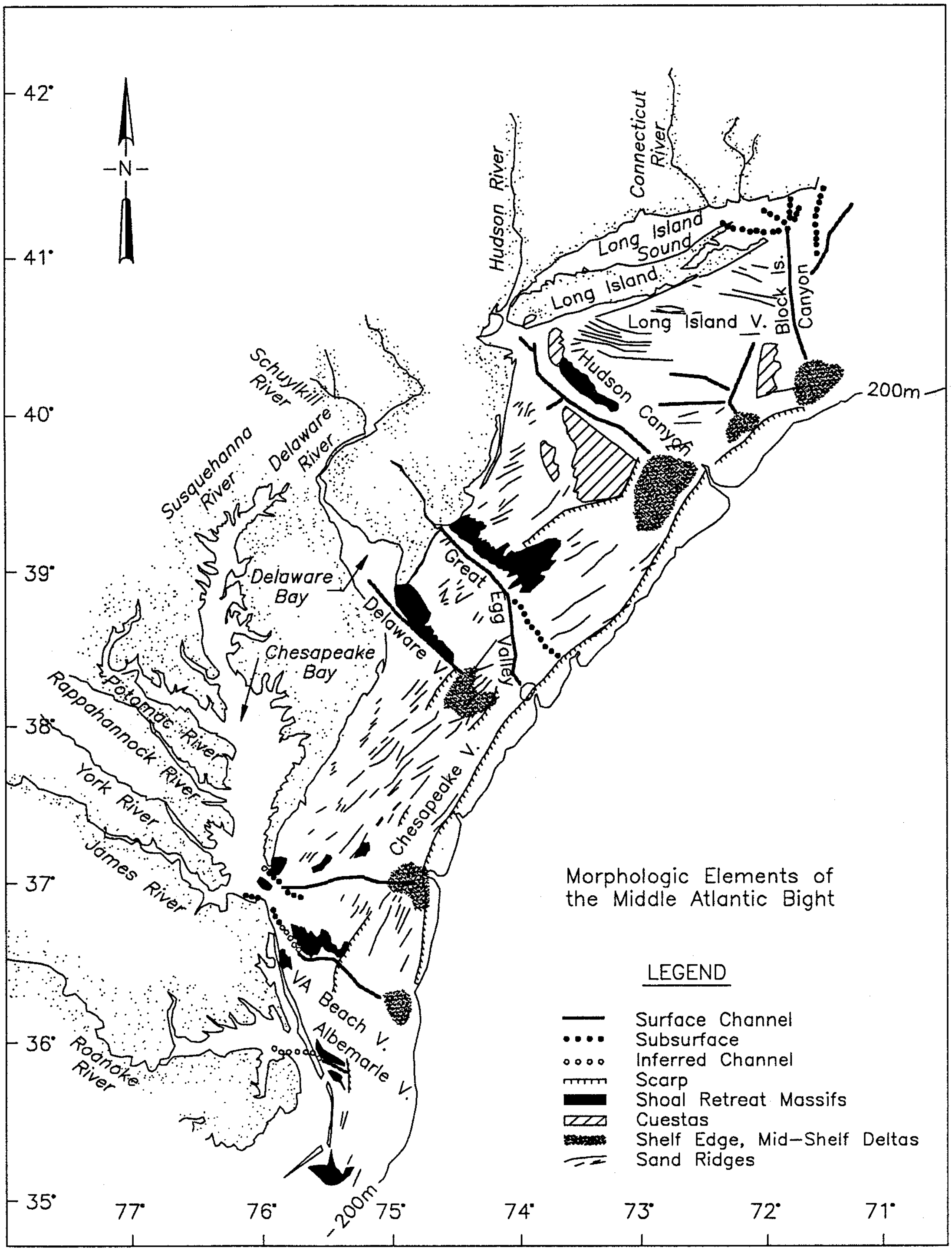


**Figure IV-2-36. Morphology of the Middle Atlantic Bight (from Swift (1976)). Sand ridges close to shore may be suitable sources of sand for beach renourishment**

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